Specification

ION MILL PROCESS WITH SACRIFICIAL MASK LAYER TO FABRICATE POLE TIP FOR PERPENDICULAR RECORDING

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to heads for high track density perpendicular magnetic recording, and more particularly relates to fabrication of poles of such heads.

Description of the Prior Art

Data has been conventionally stored in a thin media layer adjacent to the surface of a hard drive disk in a longitudinal mode, i.e., with the magnetic field of bits of stored information oriented generally along the direction of a circular data track, either in the same or opposite direction as that with which the disk moves relative to the transducer.

More recently, perpendicular magnetic recording systems have been developed for use in computer hard disk drives. A typical perpendicular recording head includes a trailing write pole, a leading return or opposing pole magnetically coupled to the write pole, and an electrically conductive magnetizing coil surrounding the write pole. In this type of disk drive, the magnetic field of bits of stored information are oriented normally to the plane of the thin film of media, and thus perpendicular to the direction of a circular data track, hence the name.

Media used for perpendicular recording typically include a hard magnetic

recording layer and a soft magnetic underlayer which provide a flux path from the trailing write pole to the leading opposing pole of the writer. Current is passed through the coil to create magnetic flux within the write pole. The magnetic flux passes from the write pole tip, through the hard magnetic recording track, into the soft underlayer, and across to the opposing pole, completing a loop of flux.

Perpendicular recording designs have the potential to support much higher linear densities than conventional longitudinal designs. Magnetization transitions on the bilayer recording disk are recorded by a trailing edge of the trailing pole and reproduce the shape of the trailing pole projection on the media plane, thus the size and shape of the pole tip is of crucial importance in determining the density of data that can be stored.

Perpendicular magnetic recording is expected to supersede longitudinal magnetic recording due to the ultra-high density magnetic recording that it enables. Increases in areal density have correspondingly required devising fabrication methods to substantially reduces the width of the P3 write pole tip **52** while maintaining track-width control (TWC) and preserving trailing edge structural definition (TED). As mentioned above, the writing process reproduces the shape of the P3 write pole projection on the media plane, so the size of the P3 limits the size of the data fields and thus the areal density. The current drive is to make P3 poles of less than 200 nm (200 X 10^{-9} meters). Making reliable components of such microscopic size has been a challenge to the fabricating process arts. This problem is made even more challenging because the P3 pole shape at the ABS is preferably not a simple rectangle, but is trapezoidal, with parallel top and bottom edges, but a bevel angle preferably of approximately 8 to 15 degrees on the side

edges. This is primarily done so that the P3 pole tip fits into the curved concentric tracks without the corners extending into an adjacent track by mistake.

Various approaches have been tried in an effort to shape such tiny components. Ion milling (IM) is a process that has been long used in the manufacture and shaping of such micro-components, but here there is the difficulty of maintaining the top edge dimension while trying to cut the side bevels. Initially, alumina was used as an IM hard mask for reliable beveled (8-15 degree) track-width definition (TWD) in the 330 - 300 nm range but was later changed to carbon to further extend the IM process to smaller dimensions. The complication in developing an IM scheme is the inability to consistently achieve a TWC process and preserve TED due to inefficient resistance of the hard mask to passivate TED. Carbon such as diamond-like-carbon (DLC) does offer a higher milling resistance over alumina to preserve TED for the 300 - 250 nm range of TWD. But there are inherent difficulties in depositing sufficient carbon film thickness to provide adequate TED protection because as the film's thickness increases, stress may result in delamination or wafer bowing. Thus the ability to extend the P3 carbon process to track-width dimension below 200 nm will be increasingly problematic. Moreover, at TWD below 200 nm, the pole piece will be fragile and removal of redeposited materials (milling nonvolatile by-products) on top and sides of the pole tip will be increasingly more difficult.

Thus, there is a need for a method for fabricating P3 pole tips for track widths less than 200 nm for perpendicular recording.

SUMMARY OF THE INVENTION

A method of fabrication of the write head of a perpendicular recording head allows for production of P3 pole tips of width less than 200 nm (200×10^{-9} meters). The method is practiced by fabricating the P2 flux shaping layer, depositing the P3 layer, depositing a layer of ion-milling resistant material, depositing at least one sacrificial layer (PS), shaping the P3 layer into P3 pole tip, removing the at least one sacrificial layer to leave the P3 pole tip, and encapsulating the P3 pole tip.

It is an advantage of the present invention that the PS layer can be fabricated with a high aspect ratio which offers higher milling resistance and allows for better passivation.

It is another advantage of the present invention that better Trailing Edge structural Definition (TED) than before can be produced.

It is a further advantage of the present invention that improved Track Width Control (TWC) can be achieved.

It is an advantage of the present invention sub-micron track widths can be obtained.

It is yet another advantage of the present invention that this process minimizes redepostion of materials.

It is a further advantage of the present invention that this process allows for adaptive track width control.

Yet another advantage of the present invention is that the write pole is preferably encapsulated and that its chances of corrosion or damage are minimized.

These and other features and advantages of the present invention will no doubt become apparent to those skilled in the art upon reading the following detailed description which makes reference to the several figures of the drawing.

IN THE DRAWINGS

The following drawings are not made to scale as an actual device, and are provided for illustration of the invention described herein.

Fig. 1 is a side cross-sectional view depicting various components of the write head of a prior art perpendicular head;

Fig. 2 is a front plan view of the Air Bearing Surface of a write head in a stage of fabrication;

Fig. 3 is a front plan view of the Air Bearing Surface of a write head in another stage of fabrication;

Fig. 4 is a front plan view of the Air Bearing Surface of a write head in yet another stage of fabrication;

Fig. 5 is a front plan view of the Air Bearing Surface of a write head in another stage of fabrication;

Fig. 6 is a front plan view of the Air Bearing Surface of a write head in yet another stage of fabrication; and

Fig. 7 is a front plan view of the Air Bearing Surface of a write head in a final stage of fabrication.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

To aid in the understanding of the structures involved in the present invention, the following discussion is included with reference to the prior art illustrated in Fig. 1.

Fig. 1 (prior art) is a side cross-sectional diagram of the write head portion of a typical prior art perpendicular magnetic head. A slider **20** has an air bearing surface (ABS) **22** which flies above the surface of a hard disk **24**. The disk **24** includes a high coercivity magnetic layer, also referred to the hard layer **26** that is fabricated on top of a magnetically soft layer **28**.

The perpendicular head **30** typically includes a read head, which is not shown here. The write head portion includes a first magnetic pole P1 **34** is fabricated upon an insulation layer **36**. An induction coil structure **38**, which includes coils **40**, is fabricated upon the P1 pole **34**. The coil turns **40** are typically formed within electrical insulation layers **42**. A second magnetic pole layer, typically termed a P2 shaping layer **44**, is fabricated on top of the induction coil structure **38**. A magnetic back gap piece **46** joins the back portions of the P1 pole **34** and the P2 shaping layer **44**, such that magnetic flux can flow between them. The P2 shaping layer **44** is fabricated so that a gap **48** is left between it and the rest of the ABS **22**, and an alumina fill is deposited across the surface of the wafer which results in filling the gap **48** in front of the P2 shaping layer **44**. A P3 layer **50**, also called a probe layer, includes a P3 pole tip **52**, and is in magnetic flux communication with the P2 shaping layer **44**. The P2 shaping layer channels and directs the magnetic flux into the P3 pole tip **52**.

The magnetic head **30** is subsequently encapsulated, such as with the deposition of an alumina layer **54**. Thereafter, the wafer is sliced into rows of magnetic heads, and the ABS surface of the heads is carefully polished and lapped and the discrete magnetic heads are formed.

Electrical current flowing through the induction coil structure **38** will cause magnetic flux **2** to flow through the magnetic poles **34, 52** of the head, where the direction of magnetic flux flow depends upon the direction of the electrical current through the induction coil. In one direction, current will cause magnetic flux **2** to flow through the P2 shaping layer **44** through the P3 layer **50** to the narrow pole tip **54** into the hard layer **24** and soft layer **28** of the hard disk **24**. This magnetic flux **2** causes magnetized data bits to be recorded in the high coercivity layer hard layer **24** where the magnetic field of the data bits is perpendicular to the surface of the disk **24**. The magnetic flux then flows into the magnetically soft underlayer **28** and disperse as they loop back towards the P1 pole **34**. The magnetic flux then flows through the back gap piece **46** to the P2 shaping layer **44**, thus completing a magnetic flux circuit. In such perpendicular write heads, it is significant that at the ABS **22**, the P1 pole **34** is much larger than the P3 pole tip **52** so that the density of the magnetic flux passing out from the high coercivity magnetic hard layer **26** is greatly reduced as it returns to the P1 pole layer **34** and will not magnetically affect, or flip, the magnetic field of data bits on the hard disk, such as bits on data tracks adjacent to the track being written upon.

Stages in the process of fabrication of a P3 pole tip for a write head for perpendicular recording are shown in FIGS. 2-7. In these figures, it will be assumed that the lower layers such as the first pole P1 **34**, the induction coil structure **38**, and insulation layer **42** (see Fig. 1) have been already formed in a conventional manner.

Figs. 2-7 show the structure as seen from the ABS. In Fig. 2, the P2 shaping layer has been deposited, but is not visible behind the alumina fill layer **48**, as the P2 layer does not extend to the ABS, as discussed above. The P3 pole tip **52** layer consists of multi-layers of high magnetic moment (B_s) and non-magnetic laminated pole material such as CoFe or CoFeN or NiFe or their alloys and Cr, Al_2O_3, Ru, etc., respectively which have been deposited, and then a layer of material which is resistant to ion milling, such as Al_2O_3 or Ta_2O_5 or SiO_xN_y or their alloys are deposited. Generally, insulation materials may be used also. This thin nonmagnetic layer will function as a CMP stop layer **60** and the "clean-up" layer. This is followed by a non-magnetic film seed layer **62** (Rh preferred). A layer of photo-resist **64** of given thickness is put down, and a cavity **66** is produced which will be filled in the next step.

In Fig. 3, the cavity has been filled with material to form a sacrificial layer, also referred to as PS **68**. The material of this sacrificial layer is preferably NiP, although other plated materials, (both non-magnetic, and magnetic, as will be discussed later) with high ion milling resistance may also be used. The photo-resist layer is then removed, resulting in the structure seen in Fig. 3. This PS **68** layer is used as an ion mill mask **70** to pattern the P3 layer **52,** (to be discussed below). In a preferred process design, the PS **68** and CMP stop layer **60** materials are resistant to ion milling and also have similar ion

milling rates, but the CMP stop layer **60** is preferred to have a slightly lower ion mill rate. In this case, when the PS **68** is trimmed to target track-width, the CMP stop layer **60** is also trimmed. The CMP stop layer **60** is used both to bevel the P3 pole tip **52** and as a CMP stop. The role of PS **68** is for patterning the write pole and transferring it to the CMP stop layer **60** and pole tip materials. The material for PS **68** is preferably non-magnetic (also the seed-layer such as Rh) so that traces of it can potentially be left in the head without interfering with the heads' performance. Moreover, it is desirable to plate PS **68** as thick as lithographically possible to achieve higher passivation and ion milling resistance.

In Fig. 4, ion milling is used to cut through the layers **52, 60, 62.** The seed-layer **62** is first removed, and then the trackwidth of PS **68** is preferably reduced before ion milling of CMP stop layer **60** and P3 pole tip **52** is started. By reducing the width of the PS layer **68,** the width of the P3 pole tip layer **52**, CMP stop layer **60** and seed layer **62** beneath are also reduced.

Next ion milling is used again to bevel the sides of the P3 pole tip **52**, as shown in Fig. 5. The sacrificial layer PS **68** and the seed layer **62** both erode slightly faster during this process, but the CMP stop layer **60,** which is preferred slightly higher in ion milling resistance than PS **68** acts as a secondary mask **72** so that the top edge of the P3 pole tip **52** is protected, as shown in Fig. 5. CMP stop layer **60** is also used as a mask to bevel the pole piece.

As the trackwidth of the write pole shrinks, re-deposition and fencing on the side wall of the write pole **52** become a problem for removal since the pole tip **52** is so small

(200 nm) and has a higher risk of being damage. In the present invention, after the P3 write pole **52** is defined, it is encapsulated with Al_2O_3 or an insulator material. The encapsulation material provides mechanical strength to the pole and minimizes it from corrosion (CoFe in the pole). As CMP is used to remove PS **68**, re-deposition and fencing are removed.

Therefore, after defining the P3 write pole **52** with ion milling, the write pole **52**, CMP stop layer **60**, remaining seed layer **62** and remaining PS **68** are encapsulated with an insulator such as alumina, which is preferably also of the same material used in the CMP stop layer **60.**

CMP is then used to remove the remaining PS **68**, and seed layer **62**. As discussed above, the encapsulating material is preferred to be similar to CMP stop layer **60**, so that as CMP is used to remove PS **68** the removal rate is selective toward PS **68** material. After a while, as CMP encounters the same material, used as the CMP stop layer **60** and encapsulating material **74**, the rate slows.

When the remaining PS layer **68** have been removed, the result is a planarized top surface of CMP stop layer **60** and encapsulating material **74** around the finished P3 pole tip **52**, whose width preferably is on the order of 200nm or less. This structure is shown in Fig. 7.

In the discussion above, it has been preferred that non-magnetic material is used, so that if the CMP does not completely remove the seed layer **62** and PS **68**, the performance of the head will not be compromised. However, if in fact the seed layer **62**

and PS **68** are completely removed, magnetic material may alternately be used for these layers **62, 68**.

Thus, the present invention fabricates a sacrificial plated NiFe layer (PS) above a full-film magnetic layer where P3 will be defined. The higher aspect ratio of the PS layer offers higher milling resistance and allows for better passivation, TED, and TWD than previously disclosed methods.

While the present invention has been shown and described with regard to certain preferred embodiments, it is to be understood that modifications in form and detail will no doubt be developed by those skilled in the art upon reviewing this disclosure. It is therefore intended that the following claims cover all such alterations and modifications that nevertheless include the true spirit and scope of the inventive features of the present invention.